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Experimental study on behavior of sidewall fires at varying height in a corridor-like structure

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Abstract

A set of experiments on sidewall fires was conducted in a small-scale corridor-like structure. The mass loss rate, ceiling jet flame length and maximum ceiling jet temperature were investigated by correlating with the distance between fire source and ceiling. The results show that as the effective ceiling height decreases, the mass loss rate increases due to the enhanced radiation heat feedbacks from the ceiling and ceiling jet flame to the fuel surface. The mass loss rates are higher for the pans with long edge attaching sidewall compared to those with short edge attaching sidewall, due to the enhanced sidewall confinement effect. A simplified equation for predicting the mass loss rate per unit area is developed involving the dimensionless effective ceiling height and the length ratio of pan edges attached and perpendicular to the sidewall. Besides, a correlation is established between the dimensionless longitudinal length of ceiling jet flame and the dimensionless heat release rate by taking into account the effects of heat release rate, effective ceiling height, pan size and layout. The maximum ceiling jet temperature rise for intermittent flame hitting the ceiling can be expressed using the similar form as the McCaffrey's model. A modified correlation for the maximum ceiling jet temperature by taking into account the effect of the pan layout and the aspect ratio of the pan edges is proposed.

Keywords: Sidewall fire; Ceiling jet; Mass loss rate; Flame length; Maximum ceiling jet temperature

1. Introduction

Fires attaching sidewalls and impinging on ceilings would lead to complex thermal and flow fields. In such a case, the ceiling heat flux might increase dramatically in the flame region and there are possibilities of flame spread at a combustible ceiling. Hence, predicting the burning rates and ceiling jet features including flame length and temperature for sidewall fires under ceilings is important to fire safety assessments. Numerous studies of ceiling jet have been reported [1–4]. However, the available models and empirical correlations of predicting the flame length under a ceiling have mostly focused on the fires remote to the sidewalls. Moreover, the widely used porous gas burners in previous researches have stable burning rates by controlling the fuel volume flow rate, which could not be influenced by the heat

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feedback from boundaries and flames, whereas the sidewall and ceiling may affect the burning behavior and flame configuration of real fires to a large extent [5].

In the impingement region of ceiling jet, the maximum temperature is critical to the fire detection systems as well as the protection of surrounding structures. Previous studies on ceiling gas temperatures have studied the flame zone and the smoke zone [6–9]. However, the effects of sidewall were not involved.

This paper focuses on the features of sidewall fires with different distances below the ceiling in a small-scale corridor-like structure model. The corridor-like structures include corridor, tunnel, subway, and long passage, etc. Compared to the idealized circular or square pool fires, rectangular and line shape fires are more common in reality [10–12]. Therefore, the aspect ratio and layout ways of rectangular fuel pan are investigated.

2. Experimental setup

Figure 1 shows the small-scale corridor-like structure model with dimensions of 2.0 m × 1.0 m × 0.5 m. The ceiling, floor and one of the sidewalls are made of 4 mm thick steel plate with 30 mm thick fire-resistant board as inner lining while the other sidewall is made of 8 mm thick fire-resistant glass for observation purposes. Methanol was used as fuel for the fire source. The fuel pans were placed attaching one of the sidewalls as shown in Fig. 1. A summary of the experimental conditions is shown in Table 1. There were five square pans with side length of 0.10, 0.15, 0.20, 0.25, 0.30 m, and five rectangular pans (0.10 m × 0.30 m, 0.15 m × 0.30 m, 0.20 m × 0.30 m, 0.25 m × 0.30 m, 0.15 m × 0.20 m). For each rectangular pan, the long and short edges were placed respectively attaching the sidewall. The effective ceiling height, H_{ef}, was defined as the distance between pan bottom and ceiling which was 0.15, 0.25, 0.35, and 0.45 m, respectively. All pans were made of 2 mm thick steel plates with 20 mm in depth. The pans were filled with 10 mm deep of fuel before ignition. The ambient temperature was recorded by a mercury thermometer before each experiment, which was ranging in 293–295 K. The typical cases were repeated for three times and the results presented good repeatability with discrepancies less than 5%.

The fuel mass versus time was recorded using a CPA34001S electronic balance manufactured by Sartorius (maximum load of 34 kg, precision of 0.1 g) with a sampling interval of 1 s. The heat release rates were obtained from the mass loss rate at the steady stage with the heat of combustion of methanol of 20 MJ/kg [5]. Two digital Panasonic cameras (HDC-TM700) with spatial resolution of 1920 × 1080 and frame rates of 25 fps were used to record the experimental process, from two sides of the model as shown in Fig. 1. The ceiling jet temperatures were measured by K-type (chromel–alumel) thermocouples with diameters of 1 mm and response time less than 1 s. Seventy thermocouples were installed 10 mm beneath the ceiling with the transverse distances from the sidewall of 1, 5, 10, 15, 20, 25, 30 cm, respectively, and 10 cm spacing at the longitudinal direction. The measuring errors of thermocouples associated with radiation were estimated using Luo's correlation [13]. According to the calculations, the errors were less than 10%. However, as the correlations in the literature were usually developed using uncorrected temperatures, the measured temperatures were directly used in the current study for comparison.

3. Results and discussion

3.1. Mass loss rate

Figure 2 shows longitudinal flame images taken by Camera 1 for 0.20 m × 0.20 m pan with different distances below the ceiling. As seen in the figure, the longitudinal length L of ceiling jet flame increases with decreasing effective ceiling height. As a result, the heat feedback to the fuel from the ambient environment including the heated sidewall, ceiling, and ceiling jet enhances, which leads to an increased mass loss rate. Karls-

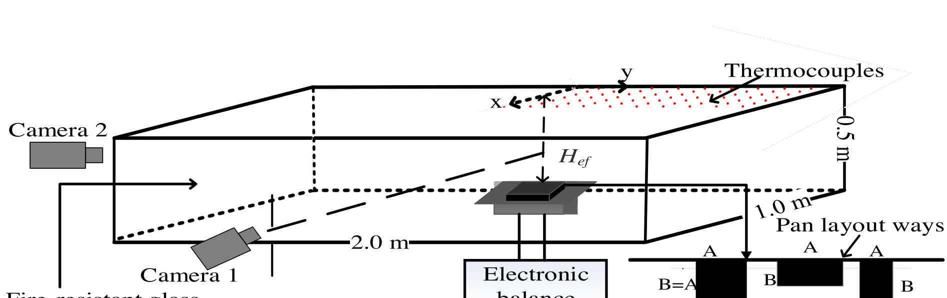

Fig. 1. Schematic of experimental apparatus.